Flight Crew Fatigue IV: Overnight Cargo Operations

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We monitored 34 B-727 crewmembers before, during, and after 8-d commercial overnight cargo trips crossing no more than one time zone per 24 h. Daytime sleep episodes were 41% shorter and were rated as poorer than nighttime sleep episodes. When the layover was long enough, crewmembers usually slept again in the evening before going back on night duty. Nevertheless, the total sleep per 24 h on duty days averaged 1.2 h less than pretrip. The circadian temperature rhythm did not adapt completely to night duty, delaying by about 3 h. Self-rated fatigue was highest around the time of the temperature minimum, which occurred near the end of the nighttime duty period. On trip days, crewmembers ate more snacks and there was a marked increase in reports of headaches, congested noses, and burning eyes. Comparisons with daytime short-haul operations confirm that a daytime rest period does not represent the same sleep opportunity as a nighttime rest period of the same duration. We examine regulatory and scheduling options, and personal countermeasure strategies, that could help to reduce sleep loss during overnight cargo operations.

IN 1987–88, the fatigue Countermeasures Program at NASA-Ames conducted a field study to assess fatigue in domestic overnight cargo operations. This study offered an opportunity to compare the affects of night vs. day flying because the same measures of fatigue were collected as in the daytime short-haul operations examined in the first NASA fatigue field study (14,15). Both types of operations included multiple flight segments per duty day and minimal time zone crossings.

In other industries, shift workers are three times as likely to complain of sleep problems as day workers, with night work being experienced as the most disruptive (1,6,37). It has been estimated that 75% of all workers experience sleepiness on every night shift, and that for at least 20% it is severe enough to cause them to fall asleep (1). A NASA-FAA study of preplanned cockpit rest in three-person long-haul flight crews (32) has compared the sleepiness and performance of crews on daytime and nighttime flights. During eastward nighttime trans-Pacific flights, sleep propensity was higher and performance was poorer (on a sustained attention, vigilance-reaction time test) than during westward daytime trans-Pacific flights. The additional challenges of night work, and their potential affects on efficiency and safety, have been highlighted in several recent publications (1,22,23,37).

Working at night creates conflict among environmental time cues to the circadian clock. It is partially reset by the altered work/rest schedule, but is continually being drawn back toward a diurnal orientation by the day/night cycle and the daytime orientation of the rest of society (1,24,37). The clock may continue to adapt progressively across a series of night duties (24). However, any adaptation is usually lost on days off, when most people revert to sleeping at night. Incomplete circadian adaptation to night work has two important consequences for fatigue and on-the-job performance. First, night workers may be working at times in the circadian cycle when their subjective fatigue and physiological sleepiness are greatest, and when they are most vulnerable to performance errors (1,7,26). Second, their daytime sleep is often compromised because they are trying to sleep when they are physiologically prepared for wakefulness, and when disturbances (noise, light, domestic or other social demands) are maximal.

Frequent changes in the sleep/wake pattern can result in chronic desynchronization of the circadian clock from the environment, and chronic desynchronization between different physiological rhythms (35). This may be a contributing factor to the long-term effects of shift work on health, including increased incidence of gastrointestinal and cardiovascular illness among shift workers (37). The quality of food available and the irregular eating habits of many shift workers probably also contribute to their increased risk of gastrointestinal problems.

Individual differences in adaptation to shift work in other industries have been reported to be correlated with several circadian characteristics and personality profiles. Better tolerance has been associated with higher amplitude circadian rhythms (30,35), and a more "evening-type"profile (2,9,19,20,21,24,27). In a group of commercial long-haul flight crewmembers, Sasaki et al. (34) found that evening-types showed lower levels of day-

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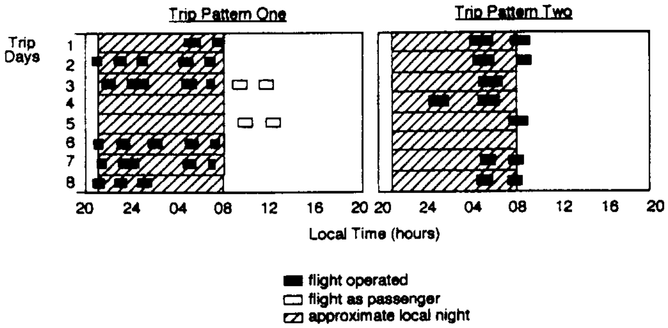

Fig. 1. The two 8-d trip patterns studied.

time sleepiness after operating an eastward flight crossing eight time zones than did morning-types. It has also been reported that individuals who score high on the extroversion and neuroticism scales of the Eysenck Personality Inventory (8) may adapt more rapidly than other personality types to schedule changes (7). In a study of Norwegian Air Force pilots, more extraverted individuals showed greater adaptation of the circadian temperature rhythm 5 d after a westward flight crossing nine time zones (16,17). These relationships account for only a very small amount of the observed individual variability and do not yet permit prediction of who is most likely to experience performance decrements as a result of fatigue.

METHODS

Two 8-d trip patterns were selected for study from the monthly bid packages of the participating airline. They were chosen, after discussion with flight crewmembers and flight operations personnel, as being representative of the two most challenging patterns that were common in the industry at that time.

All flights took place in the central and eastern U.S., crossing no more than one time zone in 24 h. Data were collected from November 1987 through December 1988. Half of the trips took place during Daylight Time, and half during Standard Time. All data were collected on Greenwich Mean Time (GMT) and converted to local time where appropriate in the analyses.

On Trip Pattern 1 **(Fig. 1)**, crews usually slept away from home between consecutive nights of flying. After 3 nights of flying, they deadheaded home (flew as passengers, but were on duty) and had about 45 h off duty before deadheading from their domicile to begin another 3 nights of flying. On Trip Pattern 2 (Fig. 1), crews usually slept at home between consecutive nights of flying. After 5 nights of flying, they arrived home and had about 45 h off duty before beginning another 2 nights of flying. Because of the 45-h break from duty, the 8 trip days were separated into duty and no-duty days in the analyses.

Two-group *t*-tests indicated that the two trip patterns differed significantly in the following: the average on-duty time; daily duty duration; layover duration; number of flight segments per night; average segment duration; number of flight hours per night; number of segments per trip; and number of hub turns per trip. The two trip patterns were comparable for the following: average off-duty time; and duration of the no-duty day (14). We were initially surprised to find that there were no significant differences between the two trip patterns in the amount of sleep per 24 h obtained by crewmembers during any stage of the study (pretrip, duty days, the no-duty day, or posttrip). Further investigation indicated that this was due to the marked day-by-day variability in duty parameters within each trip pattern. It was therefore decided to combine the data from both trips, and relate the observed changes to the day-by-day duty characteristics, rather than making global comparisons between the two trip patterns.

There were 41 Boeing-727 crewmembers (two-person crews) who volunteered to participate (39 male, 2 female). To be included in the analyses, crewmembers had to have provided logbook data for at least one pretrip night, all trip nights, and two posttrip nights. There were 20 crewmembers (87%) on Trip Pattern 1 and 14 crewmembers (78%) on Trip Pattern 2 who met this criterion. Their average age was 37.6 yr (SD 4.76 yr) and they had been with their present airline an average of 4.7 yr (SD 4.17 yr). This represents a minimum estimate of how long they had been flying overnight cargo operations. No significant differences were found (2-group *t*-tests) on a variety of demographic and personality measures between crewmembers flying the two trip patterns (14).

Unless otherwise stated, all analyses of variance (ANOVA) were within subjects. For *t*-tests, where a Levene's test revealed unequal variances, the separate *t*-test value was taken. Otherwise, the pooled *t*-test value was taken.

In addition to the logbook measures of fatigue, in this study particular attention was focused on the adaptation of the circadian clock to duty demands. Following current convention, the core temperature rhythm (measured at 2-min intervals) was used to monitor the position of the circadian clock. However, changes in the level of physical activity cause changes in temperature which are superimposed on the circadian variation. Estimating circadian phase in the presence of these masking affects is complex, particularly when people are not sleeping at the same time on consecutive days, as in the present data. To compensate for the masking of the circadian temperature rhythm by the sleep-wake cycle, a constant (0.28°C) was added to the raw temperature data for each crewmember whenever he or she was asleep. This mathematical "unmasking" procedure was based on the reported 0.28°C difference between the temperature rhythm during sleep and wake in internally desynchronized people in a time-free environment (38). Masked and unmasked temperature data for each crewmember were averaged in 20-min bins and subjected to multiple complex demodulation (29) to estimate the amplitude of the pretrip baseline temperature rhythm and the cycle-by-cycle temperature minima. The cycle-by-cycle temperature minimum was taken as the computer-selected lowest value within 12 h in the remodulated waveform. If this procedure identified two minima in 24 h, then the data and the remodulated waveform were superimposed on the sleep and nap times. If there was no clear way of discriminating between the minima (circadian or mask-

TABLE I. COMPARISONS OF SLEEP MEASURES BEFORE, DURING, AND AFTER TRIPS.

	Pretrip	Duty	No-Duty	Post	F
Sleep onset (local time)	0.55	5.72	0.69	0.56	92.90***
Wakeup (local time)	8.21	10.29	8.83	7.94	15.74***
Sleep latency (min)	14.11	17.81	25.04	21.89	1.99
Sleep duration (h)	7.46	4.56	8.09	7.21	40.90***
Total sleep/24 h	7.54	6.31	8.23	7.65	10.62***
Difficulty falling asleep?	4.21	4.12	4.23	4.04	0.35
How deep was your sleep?	3.65	3.39	4.06	3.76	5.54**
Difficulty rising?	3.48	3.31	3.38	3.69	1.60
How rested do you feel?	3.27	2.66	3.28	3.40	5.40**
Sleep rating	14.60	13.43	14.97	14.88	3.84*
# Awakenings	1.68	0.81	1.15	1.13	10.98**
Mean heart rate (bpm)	62.78	63.23	60.98	61.56	1.81
SD heart rate	6.89	6.55	6.41	6.88	0.56
Mean activity (counts/min)	2.77	2.62	1.31	1.70	1.19
SD activity	7.06	6.11	5.18	6.31	0.81
Mean temperature (°C)	36.74	36.81	36.66	36.72	3.92*
SD temperature	0.12	0.11	0.14	0.14	1.75

* 0.05 > p > 0.01; ** 0.01 > p > 0.001; *** p < 0.001.
Note: The average times of sleep onset and wakeup on trip days are somewhat misleading because of the occurrence of split sleeps.

ing), then the data for that cycle were discarded. Missing points in the raw data were replaced by linear interpolation, and all the fitted waveforms were overlaid with the original data to check that the interpolation did not introduce spurious estimates of minima. A detailed description of the affects of the unmasking procedure on the estimation of circadian parameters is contained in reference 14.

RESULTS

Sleep

Table I compares the characteristics of individual sleep episodes on pretrip, duty, no-duty, and posttrip days (one-way ANOVA with subjects treated as a random variable). Where significant differences were found, these were further examined by post hoc *t*-tests. All the comparisons discussed here were significant at least at the 0.05 level.

Sleep latency was calculated as the difference between the reported times of going to bed and falling asleep. Scores on the four sleep quality questions (rated from 1-least to 5-most) were converted so that higher values indicated better sleep, and combined to give the overall sleep rating. Heart rate, temperature, and activity data during each sleep episode were trimmed to include values from 20 min after the reported sleep onset time until 10 min before the reported wakeup time (13). Heart rate and activity data during sleep were available for 24 crewmembers (75%), and the corresponding temperature data were available for 21 crewmembers (65%).

Sleep episodes on duty days occurred later in the day, were shorter, and were rated as less restful and of lower overall quality, than sleep episodes pretrip, on the no-duty day, or postrip. They were also rated as less deep than sleep episodes on the no-duty day or posttrip. The number of reported awakenings varied significantly across pretrip, duty, no-duty, and posttrip sleep episodes. However this difference disappeared if the number of awakenings per hour of sleep was considered. The average temperature during sleep was higher for duty sleep episodes than for no-duty sleep episodes.

In the daily logbooks, it was possible to record up to two sleep episodes and two naps per 24 h. The total sleep per 24 h on duty days was less than on pretrip days, the no-duty day, or posttrip days. Since the total sleep on duty days was 1.2 h less than pretrip, crewmembers accumulated a sleep debt across trip days **(Fig. 2)**. The no-duty day permitted some recuperation, with crewmembers sleeping 41 min more per 24 h than on pretrip days, and 1.9 h more per 24 h than on duty days. The two trip patterns did not differ significantly in the amount of sleep per 24 h during any stage of the study (14). Some 54%of crewmembers averaged more than 1 h of sleep

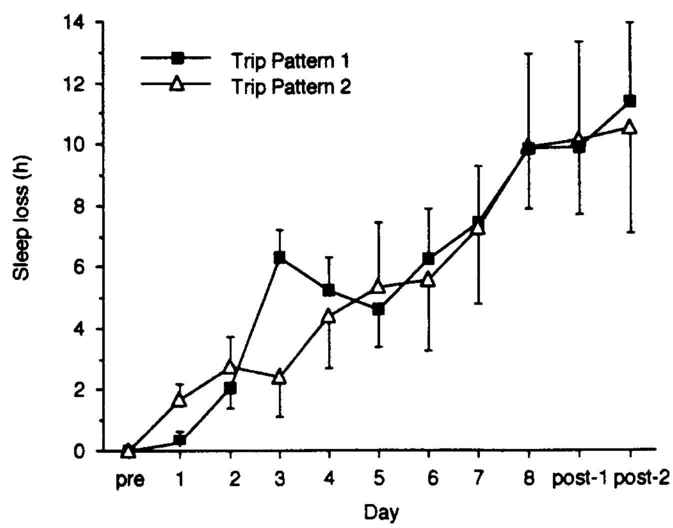

Fig. 2. Average daily sleep loss (h) across the two trip patterns. For each subject, his total sleep per 24 h on each trip day was subtracted from his average total sleep per 24 h on pretrip days, to give a daily measure of sleep loss. Average daily sleep loss was then calculated, and the values added across the consecutive trip days and posttrip days. Vertical bars indicate standard errors.

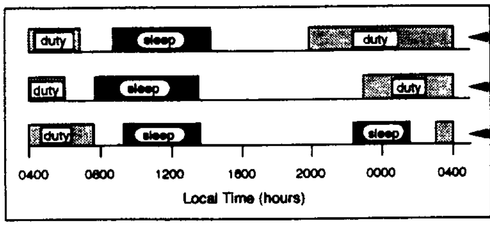

Fig. 3. Average layover and sleep timing for the most common sleep patterns during daytime layovers. On Trip Pattern 1, 96% of layovers included only one sleep episode in the morning. The remaining layovers on this trip pattern included split sleeps. On Trip Pattern 2, 37% of layovers included only one sleep episode in the morning, 58% of layovers included split sleep, and 5% of layovers included one sleep episode in the evening.

loss per 24 h across the 8-d trip patterns, and 29% averaged more than 2 h of sleep loss per 24 h. On the other hand, 15% of crewmembers reported averaging more sleep per 24 h on trip days than on pretrip days. The increasingly large standard errors across trip days in Fig. 2 indicate the increasing divergence among crewmembers in their cumulative sleep debt.

Sleep Patterns and Layover Timing

On duty days, 53% of crewmembers slept more than once in 24 h, compared with 17% on days without duty (i.e., combining pretrip, no-duty, and posttrip days). The incidence of multiple sleep episodes or naps on duty days varied markedly from day-to-day on each trip pattern, and between the two trip patterns (14). This prompted further investigation of the relationship between sleep patterns and layover timing. Naps accounted for very little of the total sleep per 24 h (3% on days with duty, 1.4% on days without duty), and were therefore not included in these analyses. The following analyses include 81 daytime layovers on Trip Pattern 1, and 78 daytime layovers on Trip Pattern 2.

Three basic sleep patterns were observed on daytime layovers: a) crewmembers slept only once in the morning; b) they slept in the morning and again in the evening (split sleep); or c) they slept only once in the evening. This third pattern was observed in only four layovers (5%) on Trip Pattern 2. The two more common sleep patterns are shown in **Fig. 3**. To test whether these different types of sleep episodes (morning or evening, single or split sleep, Trip Pattern 1 or Trip Pattern 2) were statistically distinct, one-way ANOVAs were performed **(Table II)**.

Posthoc Tukey tests with Bonferroni correction were used to compare each type of sleep episode with every other type. Single morning sleep episodes on both duty patterns were indistinguishable in duration and timing. They were longer than either the morning or the evening sleep episodes of split sleep patterns. Single morning sleep episodes also began earlier than first sleep episodes of a pair on Trip Pattern 2. When crewmembers went to sleep in the morning (for a single sleep or the first of two), they tended to wake up at around the same time (combined average 1413 hours local time), irrespective of how long they had been asleep. Wakeup times were indistinguishable for all types of morning sleep episodes (single or first of two; Trip Pattern 1 or Trip Pattern 2).

To test whether sleep patterns were affected by the timing and duration of the layover, one-way ANOVAs were performed comparing layovers with split sleep to layovers with one morning or one evening sleep episode **(Table III)**.

Posthoc Tukey tests with Bonferroni correction were used to compare the different types of layovers. Layovers containing one morning sleep episode began earlier, finished earlier, and were shorter than layovers containing split sleep. Layovers with one morning sleep episode on Trip Pattern 1 were the shortest of the identified layover categories. These analyses indicate that the decision to sleep once or twice in a layover is related to the timing and duration of the layover.

Sleep Loss and Individual Attributes

The average daily percentage sleep loss on duty days (compared for each subject to his own pretrip baseline) has been used previously as a measure of the adaptation of flight crewmembers to duty demands in a number of different types of operations (18). Correlation analyses were performed **(Table IV)** to see if this measure was related to any of the individual attributes previously reported to predict adaptation to shift work in other industries (data from 25 crewmembers). None of these relationships was significant at the 0.05 level.

Circadian Adaptation

There was no clear progressive adaptation (14) of the temperature rhythm to consecutive nights of flying (maximum of 5 consecutive nights on Trip Pattern 2). To test whether the temperature rhythm shifted in response to nighttime flying, a two-way ANOVA was performed for the masked and unmasked temperature minima comparing the two trip patterns on pretrip, duty, no-duty, and posttrip days **(Table V)**. These analyses include data for 12 crewmembers (52%) on Trip Pattern 1, and 6 crewmembers (33%) on Trip Pattern 2.

TABLE II. COMPARISON OF DIFFERENT TYPES OF SLEEP EPISODES ON THE TWO TRIP PATTERNS.

	Trip 1 AM Single	Trip 2 1st of 2	Trip 2 2nd of 2	Trip 2 AM Single	Trip 2 PM Single	F Ratio
Asleep (local h)	9.19	9.73	22.82	8.10	21.77	333.53***
Awake (local h)	14.71	13.94	2.08	14.01	1.71	585.14***
Sleep length (h)	5.44	4.30	3.29	5.79	4.02	19.05***

*** $p < 0.001$.

TABLE III. COMPARISON OF LAYOVERS CONTAINING ONE VS. TWO SLEEP EPISODES.

	Trip 1 AM Single	Trip 2 Two Sleeps	Trip 2 AM Single	Trip 2 PM Single	F Ratio
Off-duty (local h)	7.42	7.99	6.47	8.26	17.17***
On-duty (local h)	20.28	3.47	23.25	3.14	417.57***
Layover length (h)	12.86	19.48	16.68	18.88	241.95***

*** $p < 0.001$.

The two trip patterns did not have significantly different affects on the timing of the daily temperature minimum (14). For both masked and unmasked estimates, post-hoc t-tests indicated that the temperature minimum occurred later on duty days than at any other time. For both types of estimates, the timing of the temperature minimum was not significantly different on pretrip, no-duty, or posttrip days. The average times of the daily temperature minima across the study are summarized in **Table VI**.

In general, when crewmembers slept at night, the estimated time of the temperature minimum was earlier for the masked data. In contrast, when they slept during the day, the unmasked data gave the earlier estimate (14). Consequently, the masked estimates in Table VI indicate a larger delay in the temperature rhythm on duty days by comparison with pretrip (3.5 h), than the unmasked estimates (2.8 h). However, these two estimates of the circadian shift were not significantly different (paired t-test; $t = -0.62$, $p = 0.54$). Because the temperature rhythm did not adapt completely to night duty, the daily temperature minimum was occurring around the time that crewmembers came off duty **(Fig. 4)**.

Subjective Fatigue and Mood Ratings

Every 2 h while they were awake, crewmembers rated their fatigue level on a 10 cm line from "most alert" to "most drowsy." They also rated their current mood from 0 (not at all) to 4 (extremely) on 26 adjectives which have been shown to load on three orthogonal factors, designated positive affect, negative affect and activation (12). When they were on duty, crewmembers gave ratings at times when they would normally have been asleep. Thus, the affects of duty and of sampling a different part of the (partially shifted) circadian cycle are confounded. In addition, few crewmembers provided complete data and it was necessary to collapse the ratings into 4 h time-bins. Only 4 crewmembers provided fatigue and mood ratings in every 4-h time bin on pretrip, duty, no-duty, and posttrip days. Thus comparisons of time-of-day variation across different stages of the study are comparing different groups of subjects (**Table VII** and **Fig. 5**). Only crewmembers who provided data for every 4-h time bin in a given stage were included.

For ratings made on pretrip days, one-way ANOVAs showed significant time-of-of day variation in fatigue and in activation, but not in positive or negative affect. The time-of-day variations in fatigue and activation were mirror images of each another (Fig. 5), and were similar those reported for short-haul fixed-wing and helicopter pilots on pretrip days (10–12,15).

For ratings made on duty days, fatigue was highest and activation lowest in the 4-h time bin just after the temperature minimum (0830–1230 hours local time). Because of the reduction of the data into 4 h time bins, it was impossible to establish with precision the amount of shift in the fatigue and activation rhythms from pretrip to duty days. On duty days and posttrip days, positive and negative affect also showed significant time-of-day variation. Crewmembers rated their mood as most positive at the same time that they rated their fatigue as lowest.

Fatigue and mood ratings made while on duty at night (0130–0730 hours local time) were compared with those made during the day pretrip (0930–1730 hours local time). One-way ANOVAs, with subjects treated as a random variable, showed that when crewmembers were on duty at night, they rated their fatigue and negative affect as higher, and their positive affect and activation as lower, than during pretrip days **(Table VIII)**.

Caffeine Consumption

Crewmembers could obtain a thermos of coffee from operations and they were provided with a cooler of drinks (water, juice, soda, etc.) in flight (there were no cabin crew). Coffee and snack foods were available at most en route airports and full cafeteria service was available at the hub. Some crewmembers, particularly on Trip Pattern 2, brought their own food and beverages on duty with them. The number of cups of caffeinated beverages, and the time-of-day when they were con-

TABLE IV. INDIVIDUAL DIFFERENCES IN MEAN DAILY PERCENTAGE SLEEP LOSS.

	r^2
Temperature amplitude (masked)	−0.00
Temperature amplitude (unmasked)	−0.16
Neuroticism	−0.04
Extraversion	0.08
Morning/eveningness	0.27

TABLE V. EFFECTS OF NIGHT DUTY ON CIRCADIAN PHASE.

	F Pre/Duty/No-duty/Post	P Trip Patterns	F Interaction
Masked	30.34***	1.03	0.49
Unmasked	11.29***	1.36	0.36

*** $p < 0.001$.

TABLE VI. MEAN LOCAL TIMES (IN HOURS) OF THE DAILY TEMPERATURE MINIMUM.

	Pretrip	Duty	No-Duty	Post
Masked	5.06	8.56	5.67	5.44
Unmasked	5.33	8.13	6.13	6.05

sumed, were recorded in the daily logbook. All of the 34 crewmembers included in the sleep analyses consumed caffeine at some time during the study. To test whether duty demands affected caffeine consumption, a one-way ANOVA (pretrip/duty/no-duty/posttrip) was performed, with subjects treated as a random variable (**Table IX**). Caffeine consumption did not change significantly on duty days.

Meals and Snacks

The time of eating and the classification of meals (breakfast, lunch, dinner) and snacks were recorded in the daily logbook. To test whether duty demands had an effect on the number of meals or snacks eaten per day, one-way ANOVAs (pretrip/duty/no-duty/posttrip) were performed, with subjects treated as a random variable (Table IX). All the post hoc *t*-test comparisons reported here were significant at least at $p < 0.05$. Crewmembers reported fewer meals per day posttrip than either pretrip, or on duty days, or on the no-duty day. More snacks per day were reported on duty days than either pretrip, or on the no-duty day, or posttrip. The low consumption of caffeine, meals, and snacks reported posttrip probably reflects incomplete reporting posttrip.

Physical Symptoms

The logbook also contained a table for each day for noting physical symptoms (13). Of the 34 crewmembers included in the sleep analyses, 28 (82%) reported symptoms at some time during the study. The three most common symptoms were: headaches (42% of all reports, reported by 59% of crewmembers at some time during the study), congested nose (19% of all reports, reported by 26% of crewmembers at some time during the study), and burning eyes (9% of all reports, reported by 18% of crewmembers at some time during the study). The percentage of these reports which occurred on pretrip,

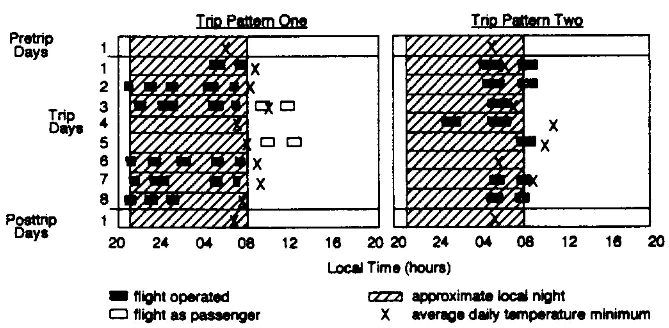

Fig. 4. Average times of the daily temperature minima (x) and flight times on the two trip patterns.

TABLE VII. TIME-OF-DAY VARIATIONS IN FATIGUE AND MOOD RATINGS ACROSS PRETRIP, DUTY, NO-DUTY, AND POSTTRIP DAYS.

	Pretrip F (n)	Duty F (n)	No-Duty F (n)	Posttrip F (n)
Fatigue	7.57 (11)***	13.01 (36)***	2.05 (6)	6.97 (8)***
Positive affect	1.54 (12)	11.46 (37)***	1.22 (8)	3.15 (8)*
Negative affect	1.62 (12)	19.57 (37)***	3.25 (8)*	5.36 (8)**
Activation	7.90 (12)***	12.28 (37)***	2.26 (8)	4.80 (8)**

* $0.05 > p > 0.01$; ** $0.01 > p > 0.001$; *** $p < 0.001$.

duty, no-duty, and posttrip days is shown in **Table X**. The incidence of headaches quadrupled on duty days, by comparison with pretrip, while the incidence of congested nose doubled, and of burning eyes increased ninefold.

Comparisons with Daytime Short-Haul Fixed-Wing Operations

Table XI compares (by two-group *t*-tests) the duty characteristics of these overnight cargo operations with those of the daytime short-haul operations described in the second paper of this series (for the trips flown by the 44 subjects included in the short-haul sleep analyses; ref 15).

As expected, the timing of the duty periods was inverted between the two types of operations. Overnight cargo crewmembers spent less time on duty each day (by an average of 3.5 h) and had longer layovers (by an average of 2.4 h) than their daytime short-haul counter-

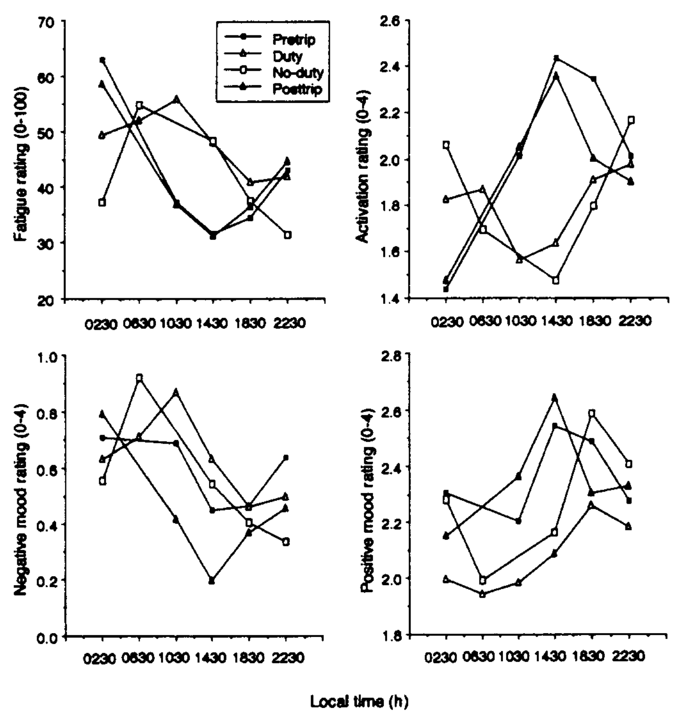

Fig. 5. Average fatigue and mood ratings at different times of day on pretrip, duty, no-duty and posttrip days. The times represent the midpoints of the 4 h data bins.

TABLE VIII. FATIGUE AND MOOD DURING DAYTIME VS. NIGHTTIME WAKE.

	Pretrip Mean	Duty Mean	F
Fatigue	33.46	51.05	53.28***
Positive affect	2.35	1.98	30.65***
Negative affect	0.49	0.68	13.26***
Activation	2.34	1.85	49.13***

*** $p < 0.001$.

TABLE X. FREQUENCY OF REPORTS OF COMMON PHYSICAL SYMPTOMS ON PRETRIP, DUTY, NO-DUTY, AND POSTTRIP DAYS.

Symptom	% Pretrip	% Duty	% No-Duty	% Posttrip
Headache	16.7	72.2	1.9	9.3
Congested nose	16.0	32.0	8.0	44.0
Burning eyes	8.3	75.0	16.7	0.0

parts. Overnight cargo duty days included fewer flight hours (by an average of 2.0) and fewer flight segments (by an average of 2.3).

Table XII compares (by two-group *t*-tests) demographic and personality measures for the two groups of crewmembers. The years of experience was taken as the largest value from among the following categories: years with the present airline; years of military experience; years of airline experience; years of general aviation experience; other.

The overnight cargo crewmembers were 5.4 yr younger on average and had 9.4 yr less experience in their present airline (a minimum estimate of how long they had been flying overnight cargo operations). There were no significant differences between the two groups in their height or weight, or in their scores on the personality inventories.

The average daily percentage sleep loss (including all sleep episodes and naps) was not significantly different during the two types of operations (two-group *t*-test, $t = -0.24$, $p = 0.81$). However, this statistic ignores whether the total sleep was obtained in one or several sleep episodes. **Fig. 6** compares the percentages of crewmembers reporting more than one sleep or nap per 24 h on daytime short-haul fixed-wing and helicopter operations (11,17) and overnight cargo operations. The particularly low incidence of multiple sleep episodes during the daytime short-haul fixed-wing operations is attributable to long duty days and short nighttime layovers which rarely allowed sufficient time for second sleep episodes or naps.

Table XIII compares the incidences of the three symptoms most commonly reported by overnight cargo flight crewmembers and daytime short-haul fixed-wing and helicopter flight crewmembers. The recurrence of the same four symptoms in each type of operation is notable given that the table of symptoms included 20 common complaints.

The responses of 41 overnight cargo and 90 daytime short-haul fixed-wing crewmembers were also compared on questions relating to: general health; increase in gastrointestinal problems on trips; appetite and dietary changes on trips; and effects of fatigue on performance (14). It was hypothesized that responses to these questions might change systematically with age. Therefore, two-way ANOVAs (operation by age) were carried out, with 5-yr age bins from 30–50, and over 50-yr-olds. The only significant finding was that overnight cargo crews reported a slight decrease in appetite on trips, whereas short-haul crews reported no change ($F = 5.84$, $0.05 > p > 0.01$). There were no significant age-related changes in the responses to these questions.

Overnight cargo crews did not increase their daily caffeine consumption during trips, in contrast to daytime short-haul crews (12,15). Both groups consumed a comparable amount of caffeine across the stages of the study (two-way ANOVA, comparing consumption on pretrip, trip, and posttrip days across the two studies: F for the overnight cargo/short-haul comparison $= 0.01$, $p = 0.95$).

DISCUSSION

This study is the first extensive documentation of the psychophysiological effects of flying overnight cargo operations, which represent a growing sector of commercial aviation worldwide. During daytime layovers, individual sleep episodes were about 3 h shorter than when crewmembers were able to sleep at night (i.e., pretrip, on the no-duty day, and posttrip). Crewmembers were three times more likely to report multiple sleep episodes (including naps) on duty days than on non-duty days (53% vs. 17%). Nevertheless, these additional sleep episodes were insufficient to prevent most crewmembers accumulating a sleep debt across trip days. Some 53% averaged more than 1 h of sleep loss on trip days, and 29% averaged more than 2 h of sleep loss. In the laboratory, reducing nighttime sleep by this amount produces cumulative reductions in alertness and performance (4,5). Reducing nighttime sleep in the laboratory by more than 2 h also causes changes in sleep architecture which indicate insufficient sleep (5). In addition to sleeping less on duty days, crewmembers also reported that their daytime sleep was lighter, less restorative, and poorer overall than nocturnal sleep. In contrast, reducing nighttime

TABLE IX. CONSUMPTION OF CAFFEINE, MEALS AND SNACKS ON PRETRIP, DUTY, NO-DUTY, AND POSTTRIP DAYS.

	Mean Pretrip	Mean Duty	Mean No-Duty	Mean Posttrip	F
Caffeine, cups/day	2.06	2.40	2.21	1.76	2.55
Meals/day	2.67	2.48	2.76	2.01	9.02***
Snacks/day	0.78	1.36	0.94	0.61	10.18***

*** $p < 0.001$.

TABLE XI. DUTY CHARACTERISTICS, OVERNIGHT CARGO VS. DAYTIME SHORTHAUL OPERATIONS.

	Mean (SD) Overnight Cargo	Mean (SD) Short-Haul	t
Local time on duty (h)	23.71 (3.53)	8.73 (2.96)	27.11***
Local time off-duty (h)	6.87 (3.01)	19.37 (2.94)	40.54***
Daily duty duration (h)	7.14 (3.69)	10.64 (2.19)	11.67***
Layover duration (h)	14.87 (3.79)	12.52 (2.52)	6.31***
Flight hours/day	2.55 (1.00)	4.50 (1.39)	14.93***
Flight segments/day	2.78 (1.30)	5.12 (1.34)	14.34***
Flight segment duration	0.90 (0.42)	1.07 (0.47)	7.26***

*** $p < 0.001$.

sleep in the laboratory results in shorter sleep latencies and deeper sleep with fewer awakenings (5). If sleep quality was indeed compromised, as the subjective ratings suggest, then this would be expected to further reduce subsequent alertness and performance, in addition to the effects of sleep loss (33).

The night off was used effectively by crewmembers to recuperate some of the sleep loss accumulated as a result of flying at night. They averaged 41 min more sleep per 24 h than pretrip and 115 min more than during daytime layovers. The night off was also strategically placed in the sequence of night duties. On Trip Pattern 1, it was clearly prudent not to add a fourth consecutive night of flying when two-thirds of the crewmembers were averaging more than 2 h of sleep loss per 24 h after 3 nights of flying. In contrast, on Trip Pattern 2, only one-third of the crewmembers were averaging more than 2 h of sleep loss per 24 h by the time of the night off, after 5 nights of flying. The average sleep debt accumulated by the end of the two 8-d patterns was not significantly different (14). Inter-individual variability in sleep loss

TABLE XII. PILOT CHARACTERISTICS, OVERNIGHT CARGO VS. DAYTIME SHORTHAUL OPERATIONS.

	Overnight Cargo Mean (SD)	Short-Haul Mean (SD)	t
Age (yr)	37.62 (4.76)	43.02 (7.65)	3.82***
Experience (yr)	12.79 (4.35)	17.07 (6.56)	3.57***
Present airline (yr)	4.74 (4.17)	14.41 (8.49)	6.60***
Height (in)	70.21 (2.82)	70.59 (1.86)	0.73
Weight (lb)	178.40 (28.29)	174.84 (16.84)	0.69
Eysenck Personality Inventory			
Neuroticism	5.09 (3.91)	6.58 (4.51)	1.49
Extraversion	11.00 (3.89)	10.91 (3.46)	0.11
Lie	3.56 (1.94)	3.41 (1.92)	0.34
Morning/Eveningness Questionnaire	54.44 (7.86)	57.64 (8.67)	1.68
Personal Attributes Questionnaire			
Instrumentality	24.50 (3.96)	23.27 (3.94)	1.36
Expressivity	22.94 (3.85)	22.34 (4.40)	0.63
i + e	3.18 (0.99)	2.84 (1.01)	1.46
Work and Family Orientation			
Mastery	21.30 (3.64)	19.95 (4.10)	1.50
Competitiveness	13.15 (4.08)	12.57 (3.49)	0.67
Work	18.24 (1.63)	17.66 (2.09)	1.32

*** $p < 0.001$.

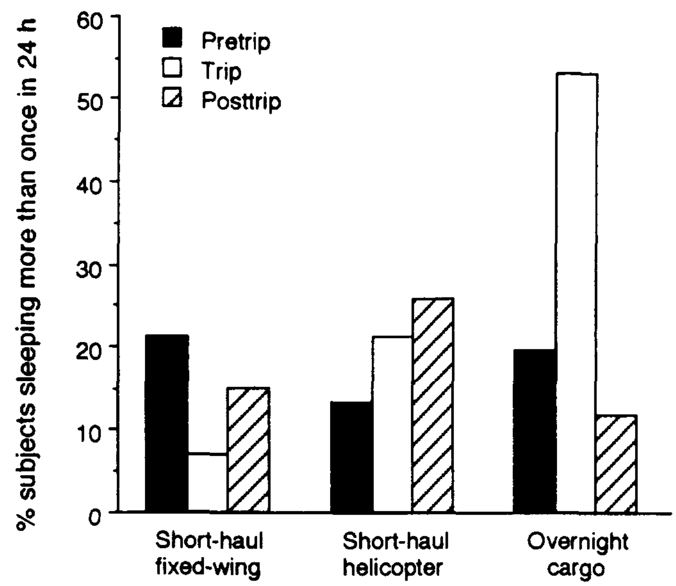

Fig. 6. Percentage of crewmembers reporting more than one sleep or nap episode per 24 h on pretrip, trip, and posttrip days. Comparison of the sleep disruption caused by nighttime flying (overnight cargo operations) and daytime flying (short-haul fixed-wing and helicopter operations).

was high and was not correlated with any of the individual attributes reported by others to predict adaptability to shift work and time zone changes, namely the amplitude of the circadian temperature rhythm, morning/eveningness, extroversion, and neuroticism.

The circadian clock apparently did not adapt completely to the reversed work-rest schedule. The daily temperature minimum delayed by about 3 h when crews flew at night, by comparison with pretrip baseline. This concurs with findings from studies of night workers in other industries (e.g., 24,35,37). The mathematical "unmasking" technique (adding 0.28°C to the raw temperature data for each crewmember whenever he was asleep) did not significantly change the estimate of the overall delay in the temperature minimum that was associated with night duty.

When crewmembers went to sleep in the morning, after a night on duty, they tended to wake up at around the same time (average 1413 hours local time), despite the fact that they had usually slept 2–3 h less than on a pretrip night. Anecdotally, they often reported waking spontaneously and not feeling well-rested. These wakeups were clustered about 6 h after the circadian temperature minimum (average masked estimate 0834, averaged unmasked estimate 0808). Similar clustering of wakeups at this time in the temperature cycle has been reported for people waking spontaneously in time-free environments, when they are living subjective "days" which do not match the period of the temperature rhythm (36). This observation has given rise to the notion of a circadian wakeup signal. Whatever its causes, the regularity of the early afternoon wakeup meant that the duration of morning sleep episodes was systematically related to how early a crewmember finished duty (multiple $r^2 = 0.44$, $F = 37.23$, $p < 0.0001$).

TABLE XIII. PERCENTAGE OF CREW MEMBERS REPORTING THE THREE MOST COMMON PHYSICAL SYMPTOMS IN DIFFERENT FLIGHT OPERATIONS.

	1st Symptom	2nd Symptom	3rd Symptom
Overnight Cargo	Headache (59%)	Congested nose (26%)	Burning eyes (18%)
Short-Haul	Headache (27%)	Congested nose (20%)	Back pain (11%)
Helicopter	Headache (73%)	Back pain (32%)	Burning eyes (18%)

Layovers in which crewmembers were able to sleep again in the evening were longer (average length about 19 h), and ended later (around 0200-0300 hours) than layovers in which they only slept in the morning. Taken together, these findings suggest two ways of increasing the amount of sleep that crewmembers can obtain during daytime layovers: a) by getting off-duty earlier, thus allowing more time for sleep before the circadian wakeup signal; and b) by lengthening the layover sufficiently to allow time for a second sleep episode before the next duty period. There is evidence from controlled laboratory studies that an early evening sleep episode can significantly improve subsequent overnight performance on a variety of tasks (28).

One physiological consideration that crewmembers need to be aware of for evening sleep is the so-called "evening wake maintenance zone" (36). This is a time in the circadian cycle when it can be very difficult to fall asleep, even with a moderate sleep debt. It lasts several hours and occurs shortly before the habitual bedtime, or centered about 8 h before the circadian temperature minimum in a time-free environment. The average pretrip bedtime in the present study was about 0030 hours, and 8 h before the temperature minimum on duty days is also around this time. This suggests that crewmembers may have difficulty falling asleep if they do not go to sleep again before about 2200 hours local time.

Fatigue and activation ratings on pretrip days showed similar time-of-day variation in this study to that seen in other field and laboratory studies (10,12,25). Flying at night altered the time-of-day variation in both variables. However, because of the reduction of the data into 4 h time bins, it was impossible to establish with precision the amount of shift from pretrip to duty days. A further complication in interpreting these data arises from the fact that subjective fatigue and activation ratings appear to comprise two components: a circadian variation which parallels the temperature cycle; and a trend associated with time since sleep (25). Both of these components were altered by night duty. Studies of night workers in other industries have found lowest subjective alertness coinciding with the minimum in body temperature (25). In the present study, when crewmembers were flying at night, highest fatigue and lowest activation were observed in the time bin from 0830–1230 hours, i.e., just after the time of the temperature minimum.

The two mood-state variables monitored, positive and negative affect, did not show significant time-of-day variation on pretrip days, but showed significant variation on duty days and posttrip. Both variables indicated more negative mood during nighttime wakefulness on trips than during daytime wakefulness pretrip. This is consistent with other studies which indicate that circadian variation is not always present in measures of mood states, but that negative changes in mood usually occur when the circadian system is disrupted (25).

Overnight cargo crews did not increase their self-reported daily caffeine consumption during trips, in contrast to crewmembers flying daytime short-haul operations (12,15). Used strategically, caffeine can be a useful fatigue countermeasure because it temporarily increases alertness. However, consumed close to bedtime, it has disruptive effects on sleep, including longer sleep latencies, lighter sleep, and more awakenings (3). These two effects may be difficult to balance for overnight cargo crews, whose low point in alertness occurs toward the end of duty, shortly before they want to fall asleep.

The eating habits of overnight cargo crews are of particular interest because of the increased risk of gastrointestinal problems among night workers (37). On duty days, they ate more snacks, although they reported eating the same number of meals per day as at home. Snacking was used to compensate for less satisfying meals, and/or it may have served as a fatigue countermeasure. Anecdotally, crewmembers said that they often snacked "for something to do." They also reported a decrease in appetite on trips, whereas daytime short-haul fixed-wing crews reported no change (15).

Comparing the overnight cargo and daytime short-haul operations studied (12,15) overnight cargo crews worked less per day, averaging 3.5 h less duty, 2.0 h less flight time, and 2.3 fewer flight segments. They also had more hours available per day for sleep (2.4 h longer layovers) and were younger (by an average of 5.4 yr), which might confer some advantage for obtaining adequate sleep. However, these apparent advantages were more than overridden by the physiological disruption associated with night work. Both groups lost a comparable number of hours of sleep per 24 h while they were on duty. In addition, whereas the daytime short-haul crews typically had one consolidated nighttime sleep episode, the daytime sleep episodes of the overnight cargo crews were much shorter and they frequently had split sleep. This is consistent with findings for night workers vs. day workers in other industries (1,6,37). Because of the incomplete adaptation of the circadian clock to night flying, the overnight cargo crews were also working around the circadian low point in alertness and performance (1,26,37). Thus, for the same amount of sleep loss, the overnight cargo crews were at greater risk of making errors than the daytime short-haul crews.

Overnight cargo crews reported more negative mood and greater fatigue on duty days than on non-duty days, in contrast to the daytime short-haul crews who reported no change (after allowing for time-of-day variation in these measures; ref 15). Overnight cargo crews were more than twice as likely to complain of headaches as daytime short-haul crews. Indeed, the incidence of headaches reported by overnight cargo crews approached that reported by helicopter crews who flew daytime air transport operations in cockpits where overheating, poor ventilation, and high levels of vibration were common (10,11). The differences in reports of physical symptoms between overnight cargo and daytime short-haul crews may be another reflection of the greater physiological challenges of night flying.

In summary, flying at night imposes different challenges than flying during the day, particularly because of the incomplete adaptation of the circadian clock to night work. Effective, safe, practical countermeasures to force the clock to adapt to night work have yet to be validated. However, the increasing demand for 24-h operations in many industries is focusing research efforts in this area (e.g., 37). At present, practical recommendations for reducing fatigue among overnight cargo crews must focus on reducing sleep loss. The current study clearly demonstrates that daytime sleep opportunities are not equivalent to nighttime sleep opportunities, and that increasing the duration of a rest period does not necessarily provide a greater amount of time for sleep. These factors should be considered in regulations governing duty/rest limitations.

Scheduling alternatives for minimizing sleep loss are also highlighted by the present study. Finishing night duty earlier permits a longer sleep episode before the circadian wakeup signal, while going back on duty later allows time for a second sleep episode. These two factors could be counterbalanced in schedule design. A night off in the middle of a sequence of night duties can be an effective countermeasure to accumulating sleep debt. It can be used strategically, by relating its position in the sequence to the rate of sleep loss imposed by a given schedule.

The knowledge and coping strategies of individual crewmembers are a key factor in fatigue management. Education programs are available to address these issues (31). For overnight cargo crews, some specific information is important. For example, they need to be aware of the alertness and performance enhancement that can result from some sleep before a period of night duty, and the performance impairment that accompanies prolonged wakefulness, particularly around the circadian low point in the early morning. The existence and timing of the evening wake maintenance zone may impact their ability to sleep in the evening, and the circadian wakeup signal may curtail their daytime sleep. Information on the strategic use of caffeine to temporarily enhance alertness during night flights, without compromising subsequent sleep, could be useful. The importance of good nutrition for night workers should also be emphasized.

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